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Adapting C2 to the 21st Century

EMPIRICAL ASSESSMENT OF A MODEL OF TEAM COLLABORATION

Track 4: Cognitive and Social Issues
Track 1: C2 Concepts, Theory, and Policy
Track 3: Modeling and Simulation

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EMPIRICAL ASSESSMENT OF A MODEL OF TEAM COLLABORATION

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A model of team collaboration was developed that emphasizes cognitive aspects of the collaboration process and includes the major processes that underlie this type of communication: (1) individual knowledge building, (2) knowledge interoperability, (3) team shared understanding, and (4) developing team consensus. This paper describes research conducted to validate this model and determine how these processes contribute to team performance by analyzing two collaborative decisionmaking tasks. Team communications that transpired during two complex problem solving situations were analyzed and coded. Data was analyzed for two teams that conducted a Maritime Interdiction Operation (MIO) and four teams that engaged in an air-warfare scenario. The MIO scenario involves a boarding team that boards a suspect ship to search for contraband cargo (e.g. explosives, machinery) and possible terrorist suspects. The air-warfare scenario involves identifying air contacts in the combat information center of an Aegis ship.

INTRODUCTION

Military forces are beginning to operate as a networked force, which allows them to plan, decide, and act collaboratively and concurrently to accomplish many tasks simultaneously. These collaborative capabilities are expected to contribute to reducing the time required to accomplish military objectives. Rapid access to current, accurate, and relevant information, and the ability to engage in real-time collaboration with other decisionmakers who are geographically distributed, have become indispensable elements of the command and control (C2) planning and decision-making process. While information access has always been critical to success in military operations, the processes embodied in recently emerging military concepts (e.g., rapid decisive operations) place an even greater emphasis on having rapid access to relevant and accurate information. These new military concepts derive their power from the effective linking or networking of the warfighting enterprise (Alberts, Gartska, and Stein, 2003). This new way of conducting business is characterized by the ability of geographically dispersed forces to create a high level of shared awareness that can be exploited to achieve rapid decisive operations.

While the U.S. has an unmatched ability to gather information on the environment, the adversary, and ourselves, we currently lack the collaborative planning capabilities (both mature systems and practiced operators) and C2 systems to use this information to enable decision superiority. The ability to quickly create and leverage superior knowledge is a critical aspect of effective military operations. This rapid formulation of knowledge and understanding of the battlespace should enable decision superiority, reduce operational risk, and increase the pace, coherence, and effectiveness of operations.

The need for rapid access to current, relevant, and accurate information is at an all-time premium — especially for military operations. Moreover, the need for expeditious transformation of that information into “actionable” knowledge is increasingly recognized by the warfighter. This exchange and transformation of information to support the military decisionmaker is facilitated by a shared information environment, and the tools that enable collaboration. New Information Technology (IT) Tools, used as part of a networked, web-based collaborative system for command and control are providing enhanced capabilities for improved decisionmaking. These tools support planning and operational processes by providing an alternative means to communicate, collaborate, and share information among operators and decisionmakers than were provided in past operational environments.

Concepts such as information and knowledge superiority, knowledge management, and effects-based operations, are important enablers of effective military operations. The need to accomplish missions efficiently and effectively, with coordinated action, points to the demand for powerful, reliable, and capable IT tools to support the military decisionmaker. These tools are expected to be critical elements of success for the decisionmaker who will be operating in a constrained battlespace, working toward the goals of achieving shared awareness, information/ decision superiority, unity of effort, and the ability to respond rapidly and autonomously.

Collaborative Tasks

Inherent in many problem solving tasks is the need for extensive collaboration and coordination across functional areas and components within the organization to accomplish the mission. Collaboration tool suites are being introduced to facilitate these information-intensive interactions to support operational planning and decisionmaking processes by providing an alternative means to communicate, collaborate, and share information among warfighters that extends what is available in today’s current operational environments. Enabled by high-speed bandwidth connectivity and electronic collaboration tools, it is anticipated that a collaborative information environment will facilitate the exchange of information among members of the Joint Force and those organizations supporting or being supported by the Joint Force. The long-term goal for operating in a collaborative environment is to reduce planning timelines while increasing organizational effectiveness.

The majority of military and business tasks today are performed by teams who collaborate to share information and task perspectives in order to reach a decision. Benefits afforded by collaboration tools that are especially germane to the military include allowing smaller deployed warfighter footprints, and capitalizing on the synergy of the total command and control infrastructure. Collaborative tools offer the added capabilities of providing the ability to share information and resources, and coordinate among individuals across geographic and temporal boundaries. Collaboration is also essential to developing shared situational awareness among heterogeneous, distributed team members.

Collaboration offers great potential to better enable decisionmakers and operators to plan, monitor, execute, and assess activities across the spectrum of activities. Capabilities afforded by collaboration tools include the ability to share applications, have a virtual workspace, use voice/audio/video, etc. Many, if not all, of the benefits of participating in a face-to-face meeting can be gained using collaborative tools: Information flows quickly, outstanding issues are raised, and a certain amount of brainstorming can occur to arrive at a decision. Additionally, all relevant users, or providers of information, reach a fuller understanding of the issues because they have seen other viewpoints and received a freer flow of information (Truver, 2001).

From a military perspective, advantages of using a collaborative environment include: fewer personnel have to be located in the area of conflict; there are enhanced opportunities to share information among planners and decisionmakers; experts in remote locations can participate in all phases of the planning, decisionmaking, and assessment process; it will increase access to many additional sources of information that previously were not possible; it should reduce the time required for the planning, decisionmaking, and assessment process.

Team collaboration and decision-making in complex, data-rich situations is being investigated to better understand the cognitive processes employed when teams collaborate to solve problems. This paper reports on research conducted under sponsorship of the Office of Naval Research (ONR) Collaboration and Knowledge Interoperability (CKI) program. The research reported in this paper applies definitions of the cognitive processes included in the model to two different decisionmaking domains. Both involve team collaboration to solve complex problems. The Maritime Interdiction Operation (MIO) task involves a Coast Guard Operation to search a suspect ship for contraband material and suspect persons. The air warfare task involves a US Navy Aegis cruiser combat information center team identifying air tracks in a Persian Gulf scenario.

Model of Team Collaboration

A cognitive model of team collaboration emphasizing the human decisionmaking processes used during team collaboration was developed by Warner, Letsky, & Cohen (2004). This model applies to collaborative problem solving and includes the major processes that underlie collaborative team problem solving, as depicted in Figure 1. These processes include (1) individual knowledge building, (2) developing knowledge inter-operability, (3) team shared understanding, and (4) developing team consensus. In this paper we describe research conducted to validate the model and determine how these processes contribute to team performance by analyzing two complex decisionmaking tasks.

Many definitions of collaboration are found in the research literature, depending on the researchers discipline and perspective. At the most fundamental level, collaboration refers to the joint effort of two or more agents to achieve a common goal (Nosek, 2003), where collaboration members construct judgments and then act on these judgments. A different definition of collaboration is “the mental aspects of joint problem solving for the purpose of achieving a shared understanding, making a decision, or creating a product.” Yet another definition states that “collaboration occurs when a group of autonomous stakeholders of a problem domain engage in an interactive process, using shared rules, norms, and structures, to act or decide on issues related to that domain” (Wood and Gray, 1991).

The types of problem-solving situations this model describes are ill-structured decisionmaking tasks, characterized by time pressure, dynamic information, with high information uncertainty, high cognitive workload (i.e., a large amount of knowledge is brought to bear to solve complex problems), and human-system interface complexity. The model focuses on three tasks; (1) team data processing, (2) developing a shared understanding among team members, and (3) team decisionmaking and course of action selection. The model consists of general inputs (e.g., task description), collaborative stages that the team goes through during the problem solving task, the cognitive processes used by the team and final team outputs, such as the selected course of action.

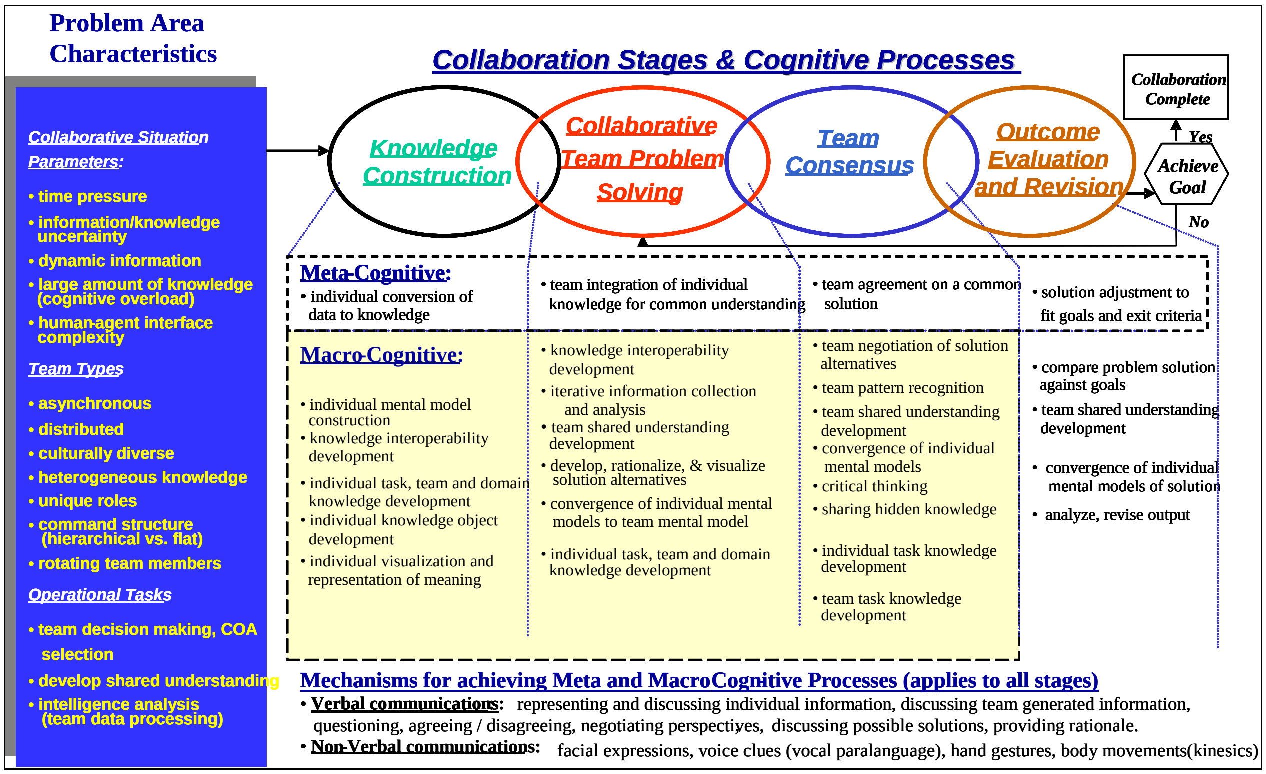

Figure 1. Model of Team Collaboration. (From Warner, Letsky, & Cowan, 2004).

Team Types. Team types described by the model include teams who operate asynchronously, whose members are distributed, and culturally diverse, where members possess heterogeneous knowledge, due to the unique roles played by each team member, and operate in a hierarchical organizational command structure, and in some situations involve rotating team members (Warner, et al., 2004). Members of both the boarding party and air warfare teams each have distinct roles and bring their respective expertise (e.g., radiological detection) to bear, and combine their heterogeneous knowledge.

Four unique but interdependent stages of team collaboration are included in the model. As depicted in Figure 1, the stages include knowledge construction, collaborative team problem solving, team consensus, and outcome and evaluation and revision. Cognitive processes within each stage are represented at two levels: meta-cognitive processes, which guide the overall problem-solving process, and macro-cognitive processes, which support team members' activities within the respective collaboration stage. The model's macro-level definition of the cognitive processes permits empirical assessment of these cognitive processes with currently available measurement techniques (e.g., verbal protocol analysis, communication analysis). Analysis of data captured from teams performing their tasks in a collaborative environment can provide valuable insight into what constitutes effective collaboration performance.

Knowledge construction begins with team members building individual task knowledge and the construction of team knowledge. Knowledge represents a pattern that connects and generally provides a high level of predictability regarding what is described or what will happen next. The focus of all the macro-level cognitive processes in the knowledge construction stage is to support individual and team knowledge development. This knowledge will be used during collaborative team problem solving sessions to develop solution alternatives to the problem.

During collaborative team problem solving sessions, team members communicate data, information and knowledge to develop solution options to the problem (Bellinger, Castro, & Mills, 2004). The majority of collaboration occurs during this stage (Warner, et al., 2004). The focus of the macro-cognitive processes during this stage is to support development of solution options for the collaborative problem.

During team consensus the team negotiates solution options and reaches final agreement by all team members on a specific option. The macro-cognitive processes support the team in reaching total agreement on the final solution to the problem. During the outcome, evaluation and revision stage the team evaluates the selected solution option against the problem-solving goal and revises the solution option if that option does not meet the goal.

METHOD

Verbatim transcripts were analyzed from two series of experiments where teams collaborated to solve a complex problem. These decisionmaking domains included Maritime Interdiction Operations (MIO) and air warfare decisionmaking scenarios. In both of these problem-solving tasks, assessment is particularly difficult because the available information is often incomplete or ambiguous. Transcripts included communications that occurred between all team members as well as with decisionmakers at the distributed sites. Our approach was to analyze and code team communications data using the cognitive process definitions developed by Warner, et al., (2004). The focus of the collaboration model is on knowledge building among the team members and developing team consensus for selection of a course of action. This research builds on previous work to validate this model (Warner, et al, 2004). The current effort uses a similar methodology applied to two different decisionmaking scenarios.

Experiment I: Maritime Interdiction Operations

An experiment was conducted to test the technical and operational challenges of developing a global Maritime Domain Security testbed. One goal was to test the applicability of using a wireless network for data sharing during a Maritime Interdiction Operations (MIO) scenario to facilitate expert reach back for radiation source analysis and biometric data analysis. This technology aims to provide networking solutions for maritime interdiction operations where subject matter experts at geographically distributed command centers collaborate with a boarding party in near real time to facilitate situational understanding and course of action selection.

The objective of this experiment was to evaluate the use of networks, advanced sensors, and collaborative technology for rapid MIO. Specifically, the ability for a boarding party to rapidly set-up ship-to-ship communications that permit them to search for radiation and explosive sources while maintaining contact with the mother ship, command and control organizations, and collaborating with remotely located sensor experts.

The boarding team boards the suspect vessel and establishes a collaborative network and then begins their respective inspections and data collection processes. The boarding officer boards the vessel with his laptop so he can collaborate with all other members of the team. This includes those who are located on the ship, but are physically spread out around different areas of the ship (while searching for contraband material and obtaining fingerprints of crew members), as well as the virtual members of the boarding team – the experts who are located at the different reach back centers. Since there are numerous commercial uses for certain radioactive sources, positive identification of the source in a short time is imperative. There is also pressure to conduct the MIO quickly so as to not detain the ship any longer than necessary.

MIO Team Members. Members of the boarding team include the following team members: 1) the Boarding Officer, a Coast Guard officer; 2) a representative from Lawrence Livermore National Labs (LLNL) with portable radiation detection devices and “reach-back” capability to LLNL; 3) a representative from the Defense Threat Reduction Agency (DTRA), who uses biometrics measurements of fingerprints and video imagery to be checked against databases at the remote facility; and 4) a representative from Special Operations Command (SOCOM), who provides guidance on handling hazardous material.

Maritime Interdiction Operations Scenario. Based on intelligence, the US Coast Guard has ordered one of its cutters to stop, board, and search a commercial vessel of foreign origin suspected of transporting uranium enriching equipment. The boarding party brings radiation detection and biometric gear, drawings of dangerous equipment and people, and video recording capability. Data is collected on suspicious material, equipment, and people and sent to specific experts at distributed reach back centers. A network extension capability was utilized from the cutter to the boarding team; the network was able to reach back to LLNL and DTRA to assist in identification of suspect cargo. Support from the National Biometric Fusion Center was used to quickly and accurately discriminate between actual vessel crewmembers and non-crew suspect persons.

The Groove collaborative workspace brought expert services into the boarding party team’s tool set and facilitated voice and text communications between all members of the virtual boarding party and physical boarding party. Remote sites were able to receive and open posted files in less then two minutes to begin their analysis. For example, expert services provided at LLNL quickly determined the need for additional data capture of longer length and different angles of approach. Requests were transmitted by text message and taken for action, and radiation source spectrum captures were made of suspect containers that were detected to have a radiation signature presence. Analysis of this data led the boarding officer to recommend that the vessel be quarantined for further inspection. The biometric team took digital prints of the crew to be compared to known criminal prints and latent prints from terrorist and crime scenes.

Cognitive Complexity of Scenarios. Scenarios used for this research focus on detecting, identifying, and interdicting nuclear materials in open waters. The critical task involves the cognitively complex issue of discrimination, that is, how to determine the presence of contraband radiological material against a background containing multiple benign radiation sources. "Smoke detectors, radiant signs, and a container load of bananas all share the ability to be moved in commercial vehicles or vessels…and all three can cause radiation detectors to alarm." (Schwoegler, 206, p.4). For example, "smoke detectors contain small amounts of americium, radiant signs glow because they contain tritium, a radioactive hydrogen isotope, and bananas, contain a small fraction of potassium-40 which emits ionizing radiation." (ibid, p. 4).

Technical expertise, provided by remotely-located experts, is required to interpret the scientific signals emitted from complex detectors to enable on-site personnel to make the fine discriminations required. Performing these complex discriminations is made possible by the collaborative capability provided by the collaborative workspace in terms of bringing remote expertise to the vessel undergoing the search and the ability to rapidly send and receive communications between a diverse team of experts who all bring their respective expertise to bear with a potentially high-threat situation. The search, identification, and final decisions need to be conducted rapidly as the economic and political ramifications of detaining a commercial cargo vessel are great. On a commercial vessel that is under way, false positives can prove economically costly and politically embarrassing.

Detecting a moving vessel emitting signs of ionizing radiation involves initial detection by a local police maritime unit. This initial detection then triggers the need for Coast Guard officers to board the vessel and take in-depth readings with portable radiation-detection instruments. These readings are immediately relayed to scientific experts, at geographically distributed locations, and the analyzed results are electronically sent back to the boarding vessel for use by first responders on the scene.

Experiment II: Air Warfare Decisionmaking

Air warfare decisionmaking is conducted in the combat information center of a Navy ship. The team has responsibility for identification of a large number of air tracks under high time pressure. These air tracks can fit multiple hypotheses regarding the level of threat they pose to the battlegroup due to the high level of ambiguity associated with the data. The nature of the data, the complex judgments required, and a sociotechnical environment that is characterized by high workload, and high stakes, all combine to create an extremely challenging problem for the air warfare team.

Incoming information arrives via various sensor systems (radar, electronic support measures system, identification friend or foe, etc.), and various reports, e.g., intelligence reports, other platforms in the area pass messages regarding situation reports on various tracks, and so on. All these reports are passed by the team member who operates that sensor, or who receives the message, to the rest of the team over any of several communications systems. These reports are generally heard by all other team members as they are all on the same communications net, although the reports are typically addressed to a specific team member/s, and sometimes they are addressed to "all." The two key decisionmakers are the commanding officer and the tactical action officer.

Reports on specific tracks are interleaved with reports on other tracks. Communications between team members are passed as soon as new information is received and updated reports are passed as soon as new information is obtained for any track. So, for example, in a series of speech turns, five separate contacts may be discussed at various levels – initial reports, updated reports, sharing information on the response, or lack of response, by the contact to some action taken by the ship, etc. Five consecutive reports could pertain to five separate tracks or all reports could pertain to one track.

Air Warfare Team Members. Six collocated team members consisted of the commanding officer (CO), tactical action officer (TAO), air warfare coordinator (AAWC), electronic warfare supervisor (EWS), identification supervisor (IDS) and tactical information coordinator (TIC). These combat information center team members also communicated with several non-collocated information sources, e.g., the battle group commander, the Saudi air tower, assets passing intelligence reports, other ships and friendly aircraft in the vicinity of the battlegroup, to gather additional information from them and keep them apprised of the unfolding scenario as they collaborated to identify air tracks.

Air Warfare Decisionmaking Scenario. The global air warfare task involves identification and responding to numerous contacts. When an aircraft (or a surface contact) is detected, CIC personnel work as a team to determine the identity and to try to determine whether or not the aircraft poses a threat. The high degree of inherent ambiguity associated with contact information can often make threat assessment a very difficult task. This is because many pieces of data fit multiple hypotheses regarding threat assessment. The global response choices (that is, engage, monitor, do nothing) are largely determined by the ship's orders and the current geopolitical situation. Specific actions (such as, change course, issue verbal warnings, illuminate with radar, challenge with other sensors, etc.) depend on the local conditions and the relative positions of the inbound contact of interest an own-ship. Determining which of these actions is likely to be effective depends on maintaining an accurate threat assessment which requires continually updating based on iterative situation assessments.

Critical air contacts are identified based on ambiguous information under time pressure to determine if the track posed a threat to the ship. One of the most challenging aspects of the combat information center teams' job is the high mental workload that is entailed when a constant stream of information must be continuously evaluated, particularly when the information often pertains to several different air contacts (or "tracks"). Relevant data/ information items must be associated with the right track number, then analyzed, synthesized and aggregated. This task places an extremely high load on working memory. The air warfare team must assess, compare, and resolve conflicting information, while making difficult judgments and remembering the status of several evolving situations. These tasks are interleaved with other tasks, such a making reports to higher authority and requesting assets.

In general, the overall task of responding to air warfare scenarios consists of situation assessment ("what's going on") and action selection ("what to do about it"). Recent theories of decision-making emphasize the importance of situation assessment for good decisionmaking in naturalistic, event-driven situations (Hutchins, 1995). Moreover, they stress that decisions regarding actions to be taken are a by-product of developing the situation awareness that precedes action selection.

Coding Process

Cognitive process coding definitions developed by Warner, et al. (2004) were used to code all speech turns. The coders attempted to develop criteria for applying the coding schema as a number of coding categories appear to have similar meanings. This codification of the coding process is part of the overall validation of the model, in that one goal is to have high inter-rater reliability between coders. It was important to pay attention to which track a team member was talking about when coding the speech turns. (This could sometimes be challenging because the last time a track was discussed may have several pages previously in the transcript and sometimes the person speaking did not always state the track number that was being discussed. In these situations the rater, by careful reading of the communications, was able to infer which track the speech turn referred to.)

The first time they discussed a track the speech turn was coded as a 2 (*individual mental model* (IMM) construction – where an individual team member, using available information, develops his/her mental picture of the problem situation). After three speech turns that discussed the same track (typically involving at least four, of the six or more team members) it was coded as a 4 (*team knowledge development* (TKM) – where all team members participate in clarifying information to build team knowledge. Once five-six team members had discussed a track, and at least 4 of the 6 team members had been involved in discussing this particular track, it was coded as a 10 – team shared understanding development – which includes discussion among all team members on a particular topic or data item.

Some exceptions to the above mentioned coding criteria include: When a team member addresses "All stations, [track # 7010 is a comm-air.]" this means he is telling all team members this evaluation of the track. Because it was addressed to all team members and it reported a higher level/ more final assessment of the track, i.e., it is a commercial airliner, this was coded as a 10. As more team members get involved in discussing a contact (i.e., more reports and/or updates have been shared among team members, the cognitive process coding category reflects a higher level of team understanding of the situation regarding that particular track.

RESULTS

Table 1 presents the cognitive process definitions developed for the model of team collaboration. We added new examples for each coding category, based on our analysis of the air warfare scenarios, to provide illustrative examples of the types of communications that fall under each of the coding categories. (The original set of cognitive process definitions included examples from a non-combatant evacuation scenario.) These examples of the coding categories are contained in Table 1.

New Coding Categories

During the analysis phase new coding categories emerged when coding the air warfare scenarios. These new categories include 21–23, miscellaneous, issue an order regarding a course of action, and request a person take some action. Examples of these categories are included in Table 1 which includes the original coding categories. *Miscellaneous* category includes getting the attention of a team member (e.g., “TAO this is EW”) prior to speaking (so as not to waste time speaking if the team member is busy and not ready to listen to the message), acknowledging a request to speak, acknowledging a message, e.g., “Copy all,” and issuing a verbal warning to the potential threat track over the radio system. Because standard operational procedure for communicating requires that significant communications be acknowledged, this wound up being the largest category of communications.

Issuing an order regarding a course of action appears to be a significant coding category. This refers to situations where a person with higher rank (e.g., commanding officer speaking to the tactical action officer (TAO), or the TAO speaking to one of the enlisted system operators, tells them to take some specific action against a potential threat track. These actions include issuing verbal warnings, illuminating or locking-on with radar, developing a firing solution, covering with missiles, etc. This category also includes responding/ reporting they have taken the action, or acknowledging the order.

Request a team member take some action refers to telling a team member to do something but it is not a direct action against a threat track. For example, “Can you try and change 7006 and 7005 to assumed hostile. I keep trying and can’t get it to do it.”

Other potential new categories include *Prodding a team member* to jog their awareness, e.g., to make sure they are following the discussion, or they push or suggest to one or more team members to go out and generate knowledge, e.g., “You should go back and see if there is …”. This person directing or suggesting might act in a role as teacher gently pushing the collaborative effort in a certain way. Another potential new category is for “*Contrarians*” when a person says “Let’s re-evaluate/ reconsider, or when the person disagrees with the current thinking of the team. This would be an “outlier” who makes the team consider another viewpoint, or “pulls back the reins.” As additional scenarios are analyzed and coded new categories may emerge.

Table 1. Cognitive Process Definitions
(From Warner, Letsky, and Cowan, 2004)

	Cognitive Process Definitions
1.	**Metacognition dti: individual conversion of data to information** = individual team member converting data to information. • “We have Don-2 bearing 086 and LN-66 bearing 097.”(converted detected radar parameters –*data* to *information* – names of radars on specific bearings) • “I am showing 8044 at 400 knots and about 27 thousand feet, possible comm-air type profile.” • “I have a second contact at 1000 feet.”
2.	**Macrocognition imm: individual mental model construction** = individual team member, using

	available information, develops his/her mental picture of problem situation. • "8030 definitely originated from Iranian airspace? The possible helo?" • "That's affirmative, sir." • "APQ-120 bears 072 off possible Foxtrot 4 Delta or Echo." • "We have 8053, that air unknown coming in up there." • "2017 is squawking a comm-air mode 3. In company with 2025, but that track is much lower than the comm-air. One at 37000, one at 8000 just came in low."
3.	**Macrocognition itk: individual task knowledge development** = individual team member asking for clarification to data or information; response to clarification. • "Do we have the track number for his CAP? I would prefer to have the track number for his CAP." • "Are you covering with birds?" • "That's affirmative, sir." • "Did you illuminate him?" (clarifying action has been taken) • "Did you establish communications with him?" • "Since he is turning to the east do you still want us to continue with level one?" (clarification of actions to be taken) • "That's a negative." (response) • "The Desert Eagle don't have that information for you right now. I asked them to get that for us. Whether the F-1s were clean or dirty."
4.	**Macrocognition tk: team knowledge development** = All team members participate in clarifying (i.e. answering a question) information to build team knowledge. • "Rainbow is sending Desert Eagle 101 and Desert Eagle 102 over to investigate track 8037 (TN 7034)." • "He looks like he is on a [air] corridor, Kuwait City to Bushehr." • "Received ESM of Cyrano 4 bears 121 off the F-1." (I) --- information • "No response track 8070." (I) --- information • "I don't have mode 3 or any other type of IFF available to me right now." • "They're going too fast for that." • "Looks like he's comm-air, he's high and looks like a comm-air profile."
5.	**Macrocognition ko: knowledge object development** = pictures, icons or standard text, developed by an individual team member or the whole team, that represents a standard meaning to the team. --- [No coded examples for air warfare]
6.	**Macrocognition vrm: individual visualization and representation of meaning** Visualization = individual team members use methods (e.g., graphs, pictures) to transfer meaning to other team members. Representation = individual team members use methods to sort data and information into meaningful chunks. --- [No coded examples for air warfare]
7.	**Metacognition cu: team integration of individual knowledge for common understanding** = all team members combine individual pieces of knowledge to achieve a common understanding. • "Track 7005 has turned west and is now inbound, sir." • "He's holding in altitude, he's not far from the air way, he flew out of good guys country and we have a comm-air radar. Let's make him assumed friend."

8.	**Macrocognition kio: knowledge interoperability development** = team members exchanging <u>*knowledge*</u> among each other. • "Desert Eagles report "tally ho" on section of two Iranian F-1s, out." ---(derived knowledge from aircraft providing a visual identification) • "We have Primus 40, bears 135, Gulfstream 2, possible Super Puma." • "It looks like the AWACs is feet dry. The CAP, composition 2, appear to be headed feet dry now." • "Doctrine won't work for 2017, make unknown assumed enemy."
9.	**Macrocognition ica: iterative information collection and analysis** = *collecting* and *analyzing* information to come up with a solution but <u>no specific solution mentioned.</u> • "No response initial warning, track 8037." • "We need a report from CAP as to whether those, upon intercept of those suspected Pumas, whether they are armed or not." • "Track 2017 deviated from known flight path still maintaining altitude and still squawking the same mode 3."
10.	**Macrocognition tsu: team shared understanding development** = discussion among <u>all</u> team members on a particular topic or data item (i.e. discussion does not involve answering questions) • "Track 8061 bearing 027 Princeton at 25 miles, 5000 feet, heading south, covering with birds." • "It looks like he is turning to the west." • "You need to watch him closely here." • "Track 8061 appeared to originate from Iran. When we picked him up he was already off the coast but he was coming south from close to the Iranian coast. I can't confirm that he came from Iran but he was coming from that direction." • "I am showing a CPA of 43 miles to the south at their current heading." • "Cyrano 4, that emitter has ceased. Last bearing for Cyrano 4 was 122." • "OK, what do we think about the Saudi CAP? Shot down, too low to communicate?" • "It looks like we still have a good track on them, 27 at 13000. Probably just poor comms with the AWACS." • "Continue to track sections of Iranian F-1s and F-4s. Approached the force with an attack profile. Interrogated level 1 with no response. They turned away from the force at a range of abut 30 miles. Continuing to track."
11.	**Macrocognition sa: develop, rationalize and visualize solution alternatives** = using data to justify a solution • "I would like fire control lock up on 7010 and I'd like to make sure he is designated as a gun target. I'd like to have two rounds of illumination prepped on mount 52." • "My intentions are to issue a warning shot with a flare if the helo proceeds to within ten nautical miles, over." • "Indicate to 7010 that if he continues to close he can expect defensive actions." • "Track number 7010 continuing inbound, request permission to engage at three nautical miles, no response to all measures, so far."
12.	**Macrocognition cmm: convergence of individual mental models to team mental model** = convincing other team members to accept specific data, information or knowledge • "OK, we need to make them assumed enemy and cover them , AAWC."
13.	**Metacognition cs: team agreement on a common solution** = all team members agree on the <u>*final*</u>

	plan. • "Listen up. 8044 is a probable comm-air, 8100 is an assumed hostile." • "8044 looks like a comm-air profile." • "ID 2010 unknown assumed friend." • "Request batteries release on track 7010, it is continuing inbound, he is at three nautical miles, request permission to engage, over."
14.	**Macrocognition tn: team negotiation of solution alternatives** = team negotiation of solution alternatives ending in a final solution *option*. (solution options are defined for each of the five components of the final plan --- i.e. personnel, transportation, weapons, critical times and detail plan) --- [No coded examples for air warfare]
15.	**Macrocognition tpr: team pattern recognition** = the team as a whole identifies a pattern of data, information or knowledge. --- [No coded examples for air warfare]
16.	**Macrocognition ct: critical thinking** = Team working together toward a common goal, whereby goal accomplishment requires an active exchange of ideas, self-regulatory judgment, and systematic consideration of evidence, counterevidence, and context, in an environment where judgments are made under uncertainty, and there is limited knowledge and time (Hess & Freeman, 2004). 1. critical thinking is measured as a *composite* of: **(Warner & Wroblewski, 2004; Hess & Freeman, 2004)** • **MCitk: individual task knowledge development** = individual team member clarifying data; asking for clarification. • **MetCcu: team integration of individual knowledge for common understanding** = one or more team members combine individual pieces of knowledge to achieve a common understanding. • **MCkio: knowledge interoperability** = team members exchanging *knowledge* among each other. • **MCsa: develop, rationalize and visualize solution alternatives** = using data to justify a solution **Note: one critical thinking frequency count = oneMCitk +oneMetCcu + MCkio + MCsa**
17.	**Macrocognition shk: sharing hidden knowledge =** individual team members sharing their knowledge through prompting by other team member(s). • "We still have no level two warnings out to those guys." • "Yes sir, we ID'd him as a com[mercial] earlier, we will go ahead and talk to him." • "I've got track 7011 ID'd as com-air. He started out at 35,000 feet, now he is descending."
18.	**Metacognition sag: solution adjustment against goal and exit criteria** = team as a whole compares complete solution option against goal and exit criteria. • "Ceased illumination 8005, maintaining lock on 8005. Turning outbound."
19.	**Macrocognition csg: compare solution options against goal(s)** = team members discuss solution options (i.e. any of the five solution components) against the scenario goal (i.e. rescue 3 red cross workers within 24 hrs). • "Ah Rainbow's holding track number 7011, low and slow and inbound. Do you desire me

	to cover with birds also?”
20.	**Macrocognition aro: analyze, revise solution** options = team members analyze final solution options (i.e. any of the five solution components) and revise if necessary. --- [No coded examples for air warfare]
21.	**Miscellaneous: misc** = acknowledging a message, asking for repeat of message, verbal warning • “Copy all, out.” • “What was your last?” • Verbal warning issued to inboard aircraft
22.	**Issue order regarding a course of action: coa** = a superior in the chain of command tells a team member to take a specific action against a possible threat track. • “Cover 8032 (TN 7013) with standard missile also generate a SWG 1A solution on him.” • “Cease illumination.” • “Let’s start level ones, 8070.”
23.	**Request take action: rta** = team member requests another team member take some action. • “Let’s investigate with CAP.” • “Confirm that tracks originating from Iranian air space are designated unknown assumed hostile.” • “Have SWC develop a Harpoon solution on him.” • “Go ahead and tag 8037 as F-1s.” • “Make 8037 and company assumed hostile.” • “Shift your focus Air to 8070, inbound helo.” • “Increase speed as well.”

For the MIO scenario, 52% of the speech turns contained content related to solving the problem; 48% involved administrative types of communications Evidence for twelve of the twenty-two cognitive processes included in the model were found. For the air warfare scenario, 99% of the speech turns contained content related to solving the problem; 1% involved administrative types of communications Evidence for fifteen of the twenty-three cognitive processes included in the model were found. Multiple occurrences for most of these cognitive processes were found in both scenarios.

Table 2 presents the cognitive process coding tallies for the four air warfare scenarios. The large number of speech turns coded as itk reflects the high degree of uncertainty inherent in air warfare decisionmaking tasks. An interesting example of sharing hidden knowledge (17) occurred when the CO issued an order to issue a verbal warning and “lock up” the inbound aircraft. The next speech turn involved the TAO replying “Yes, sir, we identified him as a com[mercial aircraft] earlier, we will go ahead and talk to him.” In this situation, the TAO was gently reminding the CO of a critical piece of information that he had forgotten. The large number of speech turns coded as categories 1-4 reflects the huge emphasis on individual knowledge construction for the air warfare task. Similarly, that examples of all six categories in the collaborative team problem solving phase – where teams integrate individual knowledge for common understanding – had many speech turns coded as these categories also indicates the large role these cognitive processes play for air warfare teams. In contrast, the small percentage of speech turns that were coded as cognitive processes associated with team consensus and outcome evaluation and revision indicated that the course of action selection phase of air warfare is not conducted in a collaborative manner.

Table 2. Cognitive Process Coding Tallies for Air Warfare and MIO Scenarios.

		Air Warfare				Maritime Interdiction		
	Macro-Cognitive Process Coding Categories	**Scen D-A**	**Scen D-B**	**CG – 59**	**DDG-54**	**Nov 06**	**June 06**	**Sept 06**
	Knowledge Construction							
1.	Data to information (dti)	1	4	-	37	2	5	-
2.	Individual mental model (imm)	8	11	18	25	1	7	8
3.	Individual task knowledge development (itk)	25	30	31	29	35	7	47
4.	Team knowledge development (tk)	11	5	18	1	3	5	8
5.	Knowledge object development (ko)	-	-	-	-	-	2	8
6.	Visualization and representation (vrm)	-	-	-	-	-	-	-
	Collaborative Team Problem Solving							
7.	Common understanding (cu)	-	6	-		2	6	7
8.	Knowledge interoperability (kio)	-	5	-	1	2	-	10
9.	Iterative collection and analysis (ica)	1	11	-	-	6	4	14
10.	Team shared understanding (tsu)	1	17	28	34	3	2	3
11.	Solution alternatives (sa)	-	3	-	-	6	-	-
12.	Convergence of mental models (cmm)	1	-	-	-	1	-	-
13.	Agreement on Common solution (cs)	-	2	-	-		-	-
	Team Consensus							
14.	Team negotiation (tn)	-	-	-	-	4	-	-
15.	Team pattern recognition (tpr)	-	-	-	-	-	-	-
16.	Critical thinking (ct)	-	-	-	-	-	-	-
17.	Sharing hidden knowledge (shk)	-	2	-	-	-	-	-
18.	Solution adjustment against goal (sag)	-	-	-	-		-	-
	Outcome Evaluation and Revision							
19.	Compare solution options against goals (csg)	-	1	-	-	-	-	-
20.	Analyze, revise solutions (aro)	-	-	-	-	-	-	-
21.	Miscellaneous (misc)	38	27	57	61	6	-	-
22.	Issue order regarding course of action (coa)	7	5	17	37	-	-	2
23.	Request take action (rta)	3	2	18	8	1	2	11
	Totals	96	131	187	233	73	40	118

Table 3 presents an excerpt of the communications coding from the MIO scenario where the team is developing solution alternatives by using data to justify a solution. First (1), individual TMs are clarifying data regarding the degree of danger inherent in the material discovered (2) and exchanging knowledge among each other, i.e., the material needs to be confiscated (3), based on information provided by one of the remote centers (the material needs to be handled carefully). An individual exchanges knowledge with other TMs (4) to develop knowledge interoperability regarding whether the Coast Guard ship has a suitable storage area for the confiscated material (5). Finally, TMs combine individual pieces of knowledge to achieve a common understanding (6) regarding the next action to be taken.

Table 3. Excerpt from MIO Scenario Communications Coding: Developing Solution Alternatives.

	MIO Team Communications		**Cognitive Process Coding**	
	Speaker		Code	
1	**DTRA**	**Cesium 137 can be used to make an RDD. If there are no explosives, then it is not configured as a weapon yet. Recommend material be confiscated.**	**MCsa**	**Develop, rationalize and visualize *solution alternatives*; using data to justify a solution**
2	**BO**	**Roger will confiscate.**	**MCitk**	***Individual task knowledge* develop-ment; individual TM clarifying data.**
3	**BO**	**Make sure you handle carefully. Cs-137 is an external gamma hazard.**	**MCkio**	***Knowledge interoperability*: TMs exchanging *knowledge* among each other.**
4	**BO**	**Roger. Will take precautions.**	**MCkio**	***Knowledge interoperability*: TMs exchanging *knowledge* among each other.**
5	**SOCOM**	**Does CG ship have proper storage area for material confiscated?**	**MCitk**	***Individual task knowledge* development: individual TM clarifying data, asking for clarification.**
6	**SOCOM**	**Search team will report size of material and its current containment condition; then make recommendations.**	**MetCcu**	**Team integration of individual TM knowledge for *common understanding*; one or more TMs combine individual pieces of knowledge to achieve common understanding.**

Table 4. MIO Scenario Communications Coding: Knowledge Interoperability Development and Agreement on a Final Plan.

	MIO Team Communications		**Cognitive Process Coding**	
	Speaker		Code	
1	**BO**	**Negative for explosives Station 2.**	**MCkio**	***Knowledge interoperability*: TMs exchanging *knowledge* among each other.**
2	**LLNL**	**Finally received RAD data from station 2.**	**MCkio**	***Knowledge interoperability*: TMs exchanging *knowledge* among each other.**
3	**SOCOM**	**Will need to resolve RAD containment hazard if it exists.**	**MetCcu**	**Team integration of individual TM knowledge for *common understanding*; one or more TMs combine individual pieces of knowledge to achieve common understanding.**
4	**DTRA**	**If you have plutonium, you need to confiscate. It's an alpha**	**MCkio**	***Iterative information collection and analysis; collecting and analyzing information to come up***

		hazard, but still must be handled carefully.		***with a solution but <u>no specific solution exists</u>.***
5	**BO**	**Roger.**	**Misc**	**Acknowledge report.**
6	**DTRA**	**By the way, if plutonium is in solid metal form, your team can handle safely with rubber gloves and a dental face mask, depending on how much is there.**	**Macica**	***Team shared understanding development – discussion among <u>all</u> team members on a particular topic or data item..***
7	**BO**	**Talking to search team to see if this is within their capabilities or if we will need outside assets.**	**MCkio**	***Iterative information collection and analysis; collecting and analyzing information to come up with a solution but <u>no specific solution exists</u>.***
8	**LLNL**	**Hazard is probably minimal, can isolate and confiscate.**	**Metcs**	***Team agreement on a common solution – all tem members agree on the <u>final plan</u>.***

DISCUSSION

Differences between the two scenarios in terms of how the team's behavior maps to the model of team collaboration were noted. One difference was that course of action selection during the air warfare tasks tends to be done less collaboratively than it is in other decisionmaking domains, e.g., a maritime interdiction operation scenario, due to the inherent time pressure to make decisions and take actions. Decisions tend to be made unilaterally by the tactical action officer or the commanding officer, (sometimes these two collaborate) but do not typically involve discussion with the rest of the team. Decisions regarding course of action selection entailed very little collaboration for the air warfare tasks due to the speed of the potential threat aircraft. When actions need to be taken very quickly in an attempt to determine the intent of an inbound track, and a series of gradually escalating actions are required, time is not available to discuss alternative courses of action.

In general, the overall task of responding to air warfare scenarios consists of situation assessment ("what's going on") and action selection ("what to do about it"). Klein (1989) found that when decisionmakers use a recognition-primed decisionmaking strategy to perform decisionmaking tasks, usually the situation itself either determines or constrains the response options and that experienced decisionmakers make up to 90% of all decisions without considering alternatives. If the situation appears similar to one that the decision maker has previously experienced, the pattern will be recognized and the course of action is usually immediately obvious. The recognition primed model of decisionmaking fuses two processes—situation assessment and mental simulation (Klein, 1993). In the simplest case the situation is recognized as familiar or prototypical, using feature matching, and the obvious response is implemented. In a more complex case the decisionmaker performs a conscious evaluation of the response, using mental simulation to uncover problems prior to implementing the response. In the most complex case the evaluation reveal flaws requiring modification, or the option is judged inadequate and rejected in favor of the next most typical reaction.

CONCLUSIONS

Analysis of data captured from teams performing their tasks in a collaborative environment can provide valuable insight into what constitutes effective collaborative performance. This understanding can then be used to develop technology to support this cognitive activity, develop tools to reduce cognitive workload, and techniques and processes to improve information exchange among collaborating members. Future plans include additional analysis for more complex scenarios and analysis of the contribution made by providing collaborative tools to support teams when performing these collaborative tasks.

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EMPIRICAL ASSESSMENT OF A MODEL OF TEAM COLLABORATION

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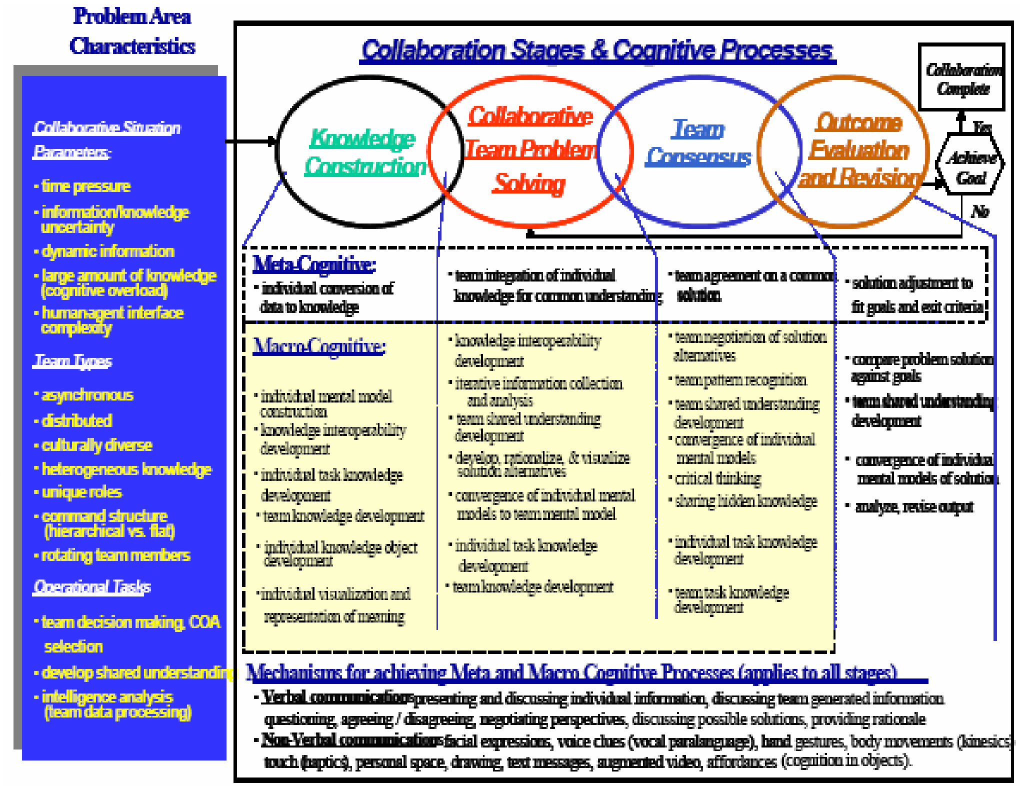
NPS Testbed for Team Collaboration Model Validation

Objective

- Better understand cognitive processes employed when teams collaborate to solve problems

Approach

- Analyze team communications data using cognitive process definitions
- Validate and refine the model of team collaboration



Data Analyzed

- Three Maritime Interdiction Operations (MIO) experiments
- Four Air Warfare scenarios
- Firefighters 9-11

Team Collaboration Model Validation

GOAL: **Understand and improve effectiveness of team decisionmaking in complex, data-rich situations by validating model of team collaboration**

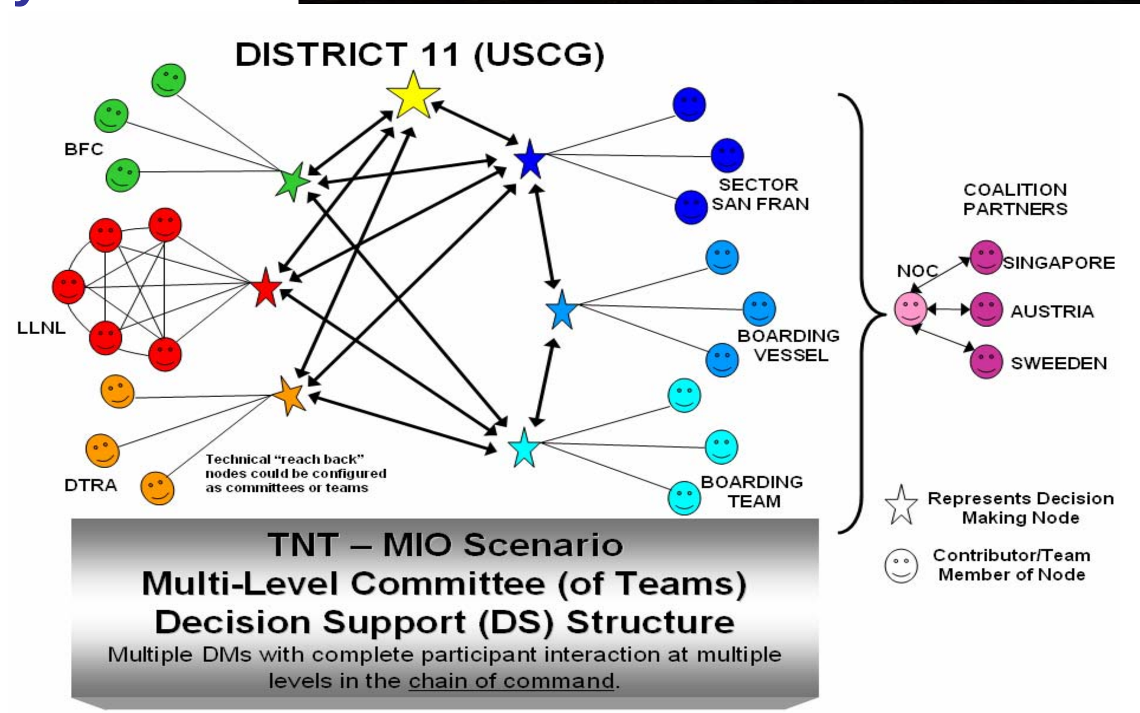
Model of Team Collaboration Defines:

- Meta-cognitive processes that guide team collaboration
- Information processing components the team performs to achieve each collaborative stage
- Communication mechanisms used by the team to build the necessary knowledge
- Emphasizes cognitive aspects of collaboration process — includes major cognitive processes that underlie this type of communication:
    - (1) Individual knowledge building
    - (2) Knowledge interoperability
    - (3) Team shared understanding and
    - (4) Team consensus (Warner, Letsky, & Cowen, 2004)
- Validate that these processes exist and how they contribute to team performance through verbal protocol analysis coding of team communications.

Types of Problem Solving Situations

- Ill-Structured Decisionmaking Tasks
- Time Pressure
- Dynamic Information
- High Information Uncertainty
- High Cognitive Workload
- Human System Interface

  Complexity



Team Types

m Adm Cebrowski Network centric warfare

- Asynchronous
- Distributed
- Culturally Diverse
- Heterogeneous Knowledge
- Unique Roles
- Command Structure
- Rotating Team Members

Operational Tasks

- Team Data Processing
- Developing Shared Situational Awareness
- Team Decisionmaking and Course of Action Selection

Office of Naval Research
Collaboration and Knowledge Management (CKM) Program
MODEL OF TEAM COLLABORATION
Focus on Macro-Cognition (September, 2005)

Problem Area Characteristics

Collaborative Situation Parameters:

- time pressure
- information/knowledge uncertainty
- dynamic information
- large amount of knowledge (cognitive overload)
- human-agent interface complexity

Team Types

- asynchronous
- distributed
- culturally diverse
- heterogeneous knowledge
- unique roles
- command structure (hierarchical vs. flat)
- rotating team members

Operational Tasks

- team decision making, COA selection
- develop shared understanding
- intelligence analysis (team data processing)

Collaboration Stages & Cognitive Processes

Knowledge Construction

Collaborative Team Problem Solving

Team Consensus

Outcome Evaluation and Revision

Achieve Goal

Yes

Collaboration Complete

No

Meta-Cognitive:

- individual conversion of data to knowledge
- team integration of individual knowledge for common understanding
- team agreement on a common solution
- solution adjustment to fit goals and exit criteria

Macro-Cognitive:

Knowledge Construction:
- individual mental model construction
- knowledge interoperability development
- individual task, team and domain knowledge development
- individual knowledge object development
- individual visualization and representation of meaning

Collaborative Team Problem Solving:
- knowledge interoperability development
- iterative information collection and analysis
- team shared understanding development
- develop, rationalize, & visualize solution alternatives
- convergence of individual mental models to team mental model
- individual task, team and domain knowledge development

Team Consensus:
- team negotiation of solution alternatives
- team pattern recognition
- team shared understanding development
- convergence of individual mental models
- critical thinking
- sharing hidden knowledge
- individual task knowledge development
- team task knowledge development

Outcome Evaluation and Revision:
- compare problem solution against goals
- team shared understanding development
- convergence of individual mental models of solution
- analyze, revise output

Mechanisms for achieving Meta and MacroCognitive Processes (applies to all stages)

- **Verbal communications:** representing and discussing individual information, discussing team generated information, questioning, agreeing / disagreeing, negotiating perspectives, discussing possible solutions, providing rationale.
- **Non-Verbal communications:** facial expressions, voice clues (vocal paralanguage), hand gestures, body movements(kinesics) touch (haptics), personal space, drawing, text messages, augmented video, affordances(cognition in objects).

Method

- Verbatim transcripts analyzed from two series of exp'ts and one real-world event where teams collaborated to solve a complex problem
  - Maritime Interdiction Operations (MIO)
  - Air warfare decisionmaking
  - Firefighters from 9-11
- In all three problem-solving tasks, assessment is difficult because available information is often incomplete or ambiguous.
  - Transcripts include communications between all team members and decisionmakers at distributed sites.
- Analyze and code team communications data using the cognitive process definitions developed by Warner, Letsky, & Cowen, 2004.
  - Focus of collaboration model is on knowledge building among team members and developing team consensus for selection of a course of action
  - Builds on previous work to validate model (Warner, et al, 2004)
  - Similar methodology applied to three different DMg tasks

Experiment I: Maritime Interdiction Operations

- Tech’l/oper’l challenges of developing global Maritime Domain Security
  - Wireless network for data sharing during MIO to facilitate reachback for radiation source analysis and biometric data analysis
  - Networking solutions for MIO where subject matter experts at geographically distributed command centers collaborate with boarding party in near real time to facilitate SA / COA selection
- Evaluate networks, adv’d sensors, and collaborative tech’y for rapid MIO
  - Rapidly set up ship-to-ship communications that permit them to search for radiation/ explosive sources while maintaining contact with mother ship, C2 organizations, and collaborating with remotely located sensor experts
- Boarding team boards suspect vessel, establishes collaborative network and begins inspections and data collection process
  - Boarding officer boards vessel with his laptop so he can collaborate with all other members of the team
  - Co-located on the ship, physically spread out (searching for contraband material and obtaining fingerprints of crew members)
  - Virtual members of the boarding team – experts at reachback centers
  - Commercial uses for certain radioactive sources, positive identification of the source in a short time is imperative
  - Pressure to conduct the MIO quickly so as to not detain the ship

MIO Team Members

- Members of the boarding team
  - Boarding Officer, a Coast Guard officer
  - Representative from Lawrence Livermore National Labs (LLNL) with portable radiation detection devices and “reach-back” capability to LLNL
  - Representative from the Defense Threat Reduction Agency (DTRA), who uses biometrics measurements of fingerprints and video imagery to be checked against databases at the remote facility
  - Representative from Special Operations Command (SOCOM), who provides guidance on handling hazardous material.

Maritime Interdiction Operations Scenario

- US Coast Guard ordered cutter to stop, board, and search commercial vessel of foreign origin suspected of transporting uranium enriching equipment
- Boarding party brings radiation detection/ biometric gear, drawings of dangerous equipment and people, and video recording capability
- Data collected on suspicious material, equipment, and people and sent to specific experts at distributed reachback centers
- Groove collaborative workspace brought expert services into the boarding party team's tool set
  - Facilitated voice and text communications between all members of the virtual boarding party and physical boarding party
- Requests, transmitted by text message -- taken for action, and radiation source spectrum captures were made of suspect containers that were detected to have a radiation signature presence
- Analysis led BO to recommend vessel be quarantined for further inspection
- Biometric team took digital prints of the crew to be compared to known criminal prints and latent prints from terrorist and crime scenes

Air Warfare Decisionmaking

- Air warfare DMg - conducted in combat information center of Navy ship
- Identification of large number of air tracks under high time pressure
  - Multiple hypotheses regarding threat level posed to the battlegroup due to high level of ambiguity associated with the data
  - Nature of the data, complex judgments required, and socio-technical environment characterized by high workload, and high stakes, create challenging problem for the air warfare team
- Incoming info arrives via various sensor systems (radar, electronic sup’t measures system, identification friend or foe, etc.), various reports, e.g., intell, other platforms in area pass messages regarding situation
- Reports passed to rest of team over any of several comm’s systems
  - Heard by all team members, reports typically addressed to specific team member/s, sometimes addressed to “all”
  - Communications passed as soon as information is received; updated reports are passed as soon as new information is obtained
- Reports on specific tracks interleaved with reports on other tracks
  - In a series of speech turns, five separate contacts may be discussed at various levels – initial reports, updated reports, sharing information on response/ lack of response, by contact to action taken by the ship, etc.

Air Warfare Team Members

- Six collocated team members consisted of
  - Commanding officer (CO)
  - Tactical action officer (TAO)
  - Air warfare coordinator (AAWC)
  - Electronic warfare supervisor (EWS)
  - Identification supervisor (IDS)
  - Tactical information coordinator (TIC)
- Combat information center team members also communicate with several non-collocated information sources
  - Battle group commander
  - Saudi air tower
  - Assets passing intelligence reports
  - Other ships and friendly aircraft in the vicinity of the battle group
- Gather additional information, keep them apprised of the unfolding scenario as they collaborated to identify air tracks.

Air Warfare Decisionmaking

- Identification/ responding to numerous air contacts: CIC personnel work as a team to identify/ determine if A/C poses a threat
  - High ambiguity often makes threat assessment a very difficult task
  - Many pieces of data fit multiple hypotheses
  - Global response choices (engage, monitor, do nothing) largely determined by ship's orders and the current geopolitical situation
  - Specific actions (e.g., change course, issue verbal warnings, illuminate with radar, challenge with other sensors, etc.) depend on local conditions, relative positions of the inbound contact and ship
    - Determining which actions is likely to be effective depends on maintaining an accurate assessment which requires continually updating based on iterative situation assessments
- Critical contacts ident'd based on ambiguous info. under time pressure
- High mental workload -- constant stream of info. must be continuously evaluated, e.g., when info often pertains to several different contacts
- Teams assess, compare, and resolve conflicting info, make difficult judgments and remember the status of several evolving situations
- Tasks interleaved with other tasks, such a making reports to higher authority and requesting assets
- Situation assessment & action selection

Coding Process

- Cognitive process coding definitions used to code speech turns
- Attempted to develop criteria for coding schema
- Codification of the coding process is part of the overall validation of the model, e.g., goal is to have high inter-rater reliability between coders
- Important to pay attention to which track a team member was talking about when coding the speech turns
- First time discuss a track -- coded as a 2 (*individual mental model* (IMM) construction – where an individual team member, using available info, develops his/ her mental picture of the problem situation)
- After three speech turns discussing the same track (typically involving at least four, of the six or more team members) it was coded as a 4 (*team knowledge development* (TKM) – where all team members participate in clarifying information to build team knowledge
- Once five-six team members had discussed a track, and at least 4 of the 6 team members had been involved in discussing this particular track, it was coded as a 10 – team shared understanding development – which includes discussion among all team members on a particular topic or data item
- Exceptions to the coding criteria include: “All stations, [track # 7010 is a comm-air.]” -- he is telling all team members this evaluation of the track.
  - Because addressed to all TMs & reported a higher level/ more final assess’t of the track, i.e., a comm-air, was coded as a 10. As more TMs discuss contact (i.e., more reports and/or updates have been shared among TMs), cognitive process coding category reflects a higher level of team understanding of the situation

New Coding Categories

- ***Issuing an order regarding a course of action*** **-- person with higher rank**
  - **Tells them to take some specific action against a potential threat track.**
    - **Issuing verbal warnings, illuminating or locking-on with radar, developing a firing solution, covering with missiles, etc.**
    - **Includes responding/ reporting have taken the action/acknowledging**
- ***Request a team member take some action*** **-- tell team member to do something**
  - **Not a direct action against a threat track.**
    - **"Can you try and change 7006 and 7005 to assumed hostile."**
- ***Prodding a team member*** **to jog their awareness**
  - **To make sure they are following the discussion**
  - **Push or suggest to one or more team members to go out and generate knowledge, e.g., "You should go back and see if there is …".**
  - **Might act in a role as teacher gently pushing collaborative effort certain way**
  - **"*Contrarians*" when a person says "Let's re-evaluate/ reconsider**
    - **Person disagrees with the current thinking of the team**
    - **"Outlier" who makes the team consider another viewpoint, or**
    - **"Pulls back the reins"**

Excerpt from MIO Scenario Communications Coding: Developing Solution Alternatives

	MIO Team Communications		Cognitive Process Coding	
	Speaker		Code	
1	DTRA	Cesium 137 can be used to make an RDD. If there are no explosives, then it is not configured as a weapon yet. Recommend material be confiscated.	sa itk	Develop, rationalize and visualize *solution alternatives*; using data to justify a solution *Individual task knowledge* development;
2	BO	Roger will confiscate.	itk	*Individual task knowledge* development; individual TM clarifying data.
3	BO	Make sure you handle carefully. Cs-137 is an external gamma hazard.	kio	*Knowledge interoperability*: TMs exchanging *knowledge* among each other.
4	BO	Roger. Will take precautions.	kio	*Knowledge interoperability*: TMs exchanging *knowledge* among each other.
5	SOCOM	Does CG ship have proper storage area for material confiscated?	itk	*Individual task knowledge* development: individual TM clarifying data, asking for clarification.
6	SOCOM	Search team will report size of material and its current containment condition; then make recommendations.	cu	Team integration of individual TM knowledge for *common understanding*; one or more TMs combine individual pieces of knowledge to achieve common understanding.

MIO Scenario Communications Coding: Knowledge Interoperability Development and Agreement on a Final Plan

MIO Team Communications		Cognitive Process Coding	
Speaker		Code	
BO	Negative for explosives Station 2.	kio	*Knowledge interoperability*: TMs exchanging *knowledge* among each other.
LLNL	Finally received RAD data from station 2.	kio	*Knowledge interoperability*: TMs exchanging *knowledge* among each other.
SOCOM	Will need to resolve RAD containment hazard if it exists.	cu	Team integration of individual TM knowledge for *common understanding*; one or more TMs combine individual pieces of knowledge to achieve common understanding.
DTRA	If you have plutonium, you need to confiscate. It's an alpha hazard, but still must be handled carefully	ica	*Iterative information collection and analysis; collecting and analyzing information to come up with a solution but no specific solution exists.*
BO	Roger.	Misc	Acknowledge report.

MIO Scenario Communications Coding:

Knowledge Interoperability Development and Agreement on a Final Plan (cont'd)

DTRA	By the way, if plutonium is in solid metal form, your team can handle safely with rubber gloves and a dental face mask, depending on how much is there.	tsu	*Team shared understanding development – discussion among all team members on a particular topic or data item.*
BO	Talking to search team to see if this is within their capabilities or if we will need outside assets.	ica	*Iterative information collection and analysis; collecting and analyzing information to come up with a solution but no specific solution exists.*
LLNL	Hazard is probably minimal, can isolate and confiscate.	cs	*Team agreement on a common solution – all tem members agree on the final plan.*

		Air Warfare Scenarios				MIO Scenarios			Firefighting
	Macro-Cognitive Process Coding Categories	Scen D-Run A	Scen D-Run B	CG - 59	DDG-54	Nov 06	June 06	Sept 06	Firefight-ers 9-11
	Knowledge Construction								
1.	Data to information (dti)	1	4	-	37	2	5	-	2
2.	Individual mental model (imm)	8	11	18	25	1	7	8	14
3.	Individual task knowledge development (itk)	25	30	31	29	35	7	47	325
4.	Team knowledge development (tk)	11	5	18	1	3	5	8	210
5.	Knowledge object development (ko)	-	-	-	-	-	2	8	0
6.	Visualization and representation (vrm)	-	-	-	-	-	-	-	0
	Collaborative Team Problem Solving								
7.	Common understanding (cu)	-	6	-		2	6	7	16
8.	Knowledge interoperability (kio)	-	5	-	1	2	-	10	8
9.	Iterative collection and analysis (ica)	1	11	-	-	6	4	14	0
10.	Team shared understanding (tsu)	1	17	28	34	3	2	3	6
11.	Solution alternatives (sa)	-	3	-	-	6	-	-	13
12.	Convergence of mental models (cmm)	1	-	-	-	1	-	-	22
13.	Agreement on Common solution (cs)	-	2	-	-		-	-	1

	Team Consensus	Air Warfare Scenarios				MIO Scenarios			Firefighting
14	Team negotiation (tn)	-	-	-	-	4	-	-	1
15	Team pattern recognition (tpr)	-	-	-	-	-	-	-	3
16	Critical thinking (ct)	-	-	-	-	-	-	-	3
17	Sharing hidden knowledge (shk)	-	2	-	-	-	-	-	5
18	Solution adjustment against goal (sag)	-	-	-	-		-	-	0
	Outcome Evaluation and Revision								
19	Compare solution options against goals (csg)	-	1	-	-	-	-	-	2
20	Analyze, revise solutions (aro)	-	-	-	-	-	-	-	1
21	Miscellaneous (misc)	38	27	57	61	6	-	-	849
22	Issue order regarding course of action (coa)	7	5	17	37	-	-	2	92
23	Request take action (rta)	3	2	18	8	1	2	11	53
	Totals	96	131	187	233	73	40	118	1626/ 777

Model of Team Collaboration: Validation

- Codes used by Firefighters
  - 19 out of the 23 cognitive processes in the model (all codes except:)
    - ***knowledge object development*** (ko)- requires pictures and icons
    - ***individual visualization and representation*** of meaning (vrm)- requires visual aids
    - ***iterative information collection and analysis*** (ica)- collect and analyze information without mentioning a solution
    - ***solution adjustment against goal*** and exit criteria (sag)- compares solution option against goal and exit criteria
  - Did not pertain to FDNY radio communication but still pertain to other team collaboration environments and should not be eliminated from the collaboration model

Model of Team Collaboration: Validation

Divide 2 hours, 21 minutes of recordings → problems faced

- Larger problem of Search and Evacuation – never got to final stages because the buildings collapsed
- Broken up into phases to represent the mental model within which the FDNY was working
- Divide into smaller problems

1. What happened? Create a mental model

   Time period: 0846-0902

1. Evacuate South Tower after the North had been hit?

   Time period: 0902-0958

1. How to divide units between the two towers?

   Time period: 0958-1028

1. Evacuate the North Tower after the South collapsed?

   Time period: 1028-1107

Model of Team Collaboration: Validation

- Trends in the codes, 1620 total speech turns
  - 849 (52.41%) miscellaneous, removed for the following percentages leaving 771 total codes
  - 325 (42.15%) itk – *iterative team knowledge development*
    - asking lots of questions, how to alleviate questions and therefore message traffic?
  - 210 (27.24%) tk – *Developing team knowledge*
    - Sharing knowledge with fellow firefighters and passing knowledge back to the dispatcher
  - 92 (11.93%) coa – *Course of action*
    - Telling the dispatcher and/or other responding units what to do
  - 53 (6.87%) rta – *Request take action*
    - Requesting something of the dispatcher or responding units
  - 22 (2.85%) cmm — *Constructing team mental model*
  - 16 2.08%) cu – Developing *common understanding*
  - 14 (1.82%) imm – *individual mental model*
    - Individuals contributing to the team's mental model

Model of Team Collaboration: Validation

- Inter-rater Reliability Analysis
  - Two coders, test subjectivity of model's codes
  - 34 out of 1626 codes (4.37%) were disagreements
    - Discussed differing opinions to reach an agreement with the other coder
  - 49 out of 1626 codes (6.31%) were decided upon after a discussion between the coders
    - One or both of the coders was unsure of how to code the communication turn and left it to discuss further with the other coder.
- In total, did not completely agree on 10.68% of codes
- Reliable 89.32% of the codes

Adherence to SOP

- Minor Deviations, SOP Deviation #1
  - ID speaker and addressee
  - Requesting ambulances and units
  - Casual communication
  - 10 codes
- Major Deviations, SOP Deviation #2
  - Unit to Unit transmissions
  - Use first names
- Major Deviations, SOP Deviation #3
  - Urgent Radio Messages (24 messages identified as urgent)
  - Mayday Radio Messages (3 messages identified as mayday)
- Department-wide Recall
  - Never used before
  - Unclear as to where to go, what to do


Situational Awareness
NOC
Bay Brg
Broadway
Coast Guard
Otis Dr
Message Box
Info
Alerts
Preferences
Device State Change
2004.01.01 Thu 16:21:57
PelcoNet 300 Homepage (Server Push) - Microsoft Internet Explorer
Server Pushed Video
Snapshot
Select path
Video Streaming
Stiletto 192.168.0.88
Google

Discussion

- Differences between three scenarios - how the team's behavior maps to the model
  - Course of action selection is done less collaboratively in tactical domains, due to inherent time pressure to make decisions and take actions
    - Decisions made unilaterally by tactical action officer or commanding officer -- do not typically involve discussion with the rest of the team.
    - Decisions regarding course of action selection entailed very little collaboration for air warfare tasks due to the speed of the potential threat aircraft.
  - When actions need to be taken very quickly in an attempt to determine the intent of an inbound track, time is not available to discuss alternative courses of action
- Air warfare consists of situation assessment ("what's going on") and action selection ("what to do about it")
  - Decisionmakers use a recognition-primed decisionmaking strategy (Klein, 1989)
    - Situation itself either determines or constrains the response options
    - Recognition primed model of decisionmaking fuses two processes — situation assessment and mental simulation (Klein, 1993)
      - Simplest case the situation is recognized as familiar or prototypical, using feature matching, and the obvious response is implemented
      - More complex case -- decisionmaker performs conscious evaluation of response, using mental simulation to uncover problems prior to implementing
      - In most complex case -- evaluation reveals flaws requiring modification, or option is judged inadequate/rejected in favor of next typical reaction
- Experienced DMs make 90% of all decisions w/o considering alternatives
    - If situation appears similar to one previously experienced, pattern will be recognized and COA is usually immediately obvious

Adherence to SOP- Mayday

Type of Mayday Message	FDNY Communications	
	Speaker	
Imminent collapse feared	N/A	
Structural collapse has occurred	FIELD	Engine 3-9 acting, report on the 22nd floor, reporting a floor collapse at that location, K.
A firefighter is unconscious or suffers a life threatening injury	FIELD	We have a medical emergency, possible heart attack, firemen, we're on the bulkhead, west, requesting oxygen for the firemen, K.
A firefighter becomes aware that another firefighter is missing	N/A	
A firefighter becomes trapped or lost	-	A civilian came on the radio asking for help because they were trapped in the rubble after the South Tower collapsed. While the civilian did not know about the correct use of “mayday” the dispatcher relayed the message saying, “transmitting a mayday.”

Adherence to SOP- Urgent

Type of Urgent Message	FDNY Communications	
	Speaker	
A firefighter suffers an injury that is not life threatening, but requires medical attention and hospital care	DISPATCH	Manhattan to Field Comm., urgent.
	FIELD	Receive, Manhattan, Field Comm.
	DISPATCH	Tower No. 2, 19th floor, firefighter down. Tower No. 2, 19th floor, firefighter down.
	FIELD	Field Comm. Received.
Discovery of a structural problem indicating the danger of collapse	FIELD	Engine 3-9 acting, report on the 22nd floor, reporting a floor collapse at that location, K.
	FIELD	Marine 1 to Manhattan with an urgent message, K.
	DISPATCH	Unit with an urgent message, K.
Fire is entering an exposure to a degree that any delay may considerably enlarge the fire problem	FIELD	This is Marine 1, we’re in the river. You’ve got fire out of the north side and now coming out of the west side of the World Trade Center, the west side.
Report of apparatus breakdown while unit is responding to an alarm	FIELD	Engine 317 to Manhattan, urgent.
	DISPATCH	Engine 3-1-7, go.
	FIELD	I’ve got… from the Port Authority telling me that the elevators are on the 44th floor. Don’t use them, they’re about to come down.
Loss of water which would endanger firefighters	DISPATCH	Engine 33 urgent, go.
	FIELD	Engine 22 is being manned by an off-duty member form Rescue 1. Be advised it appears that we have lost water pressure down in lower Manhattan. Can you have Marine 1 or any other available fire boat respond to Vescey Street on the West Side? We're going to need water supply into the area, K.

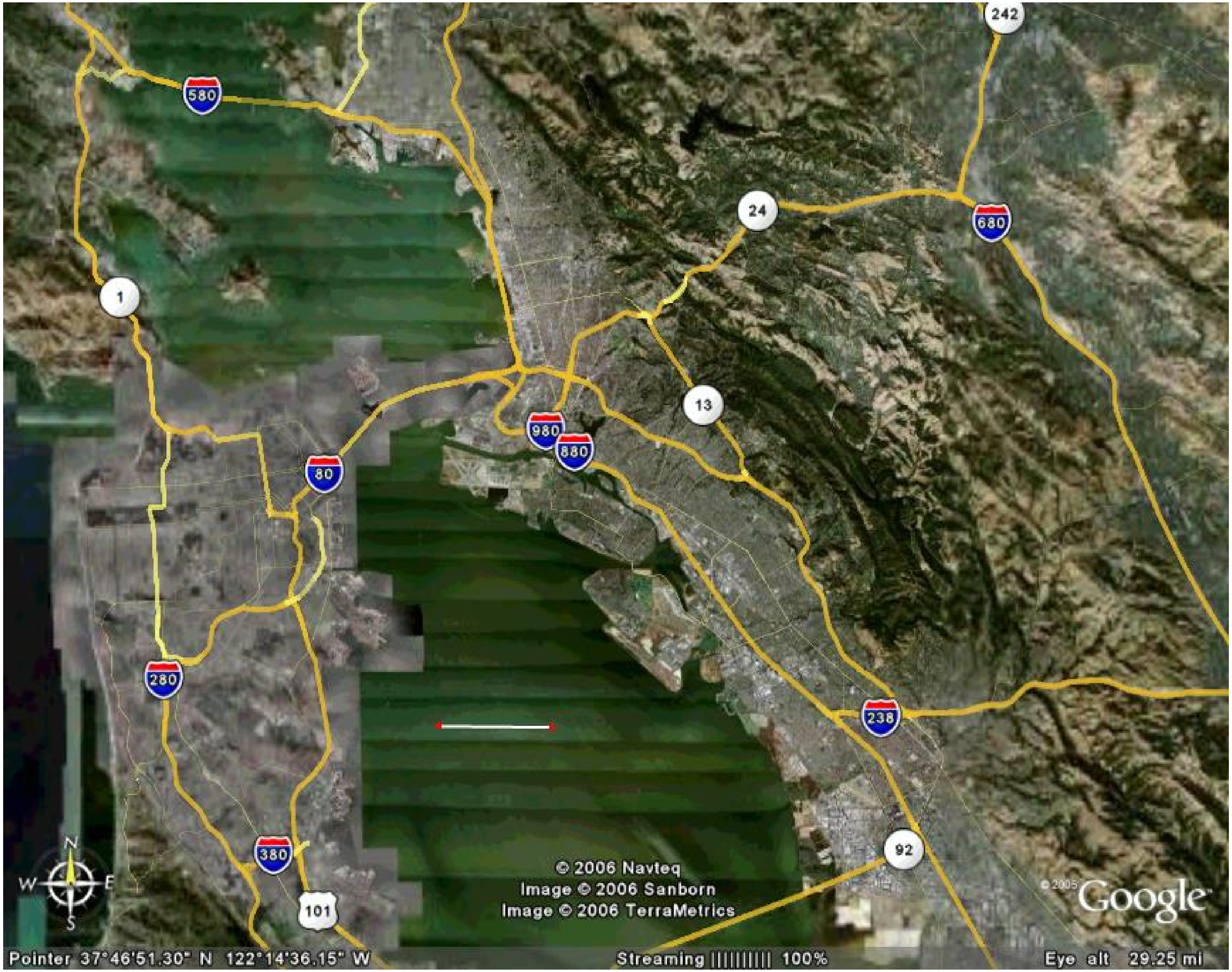
Loss of SA

- Minor Losses
  - Vague, inaccurate information
    - Reporting floor numbers
    - Referring to the two towers
- Major Losses
  - After the South Tower collapsed
    - Who survived? Field Comm?
  - After the North Tower collapsed
    - Where were the responding units? Who was in which tower?

  → Made rescuing those trapped very difficult

Loss of SA

SITUATIONAL AWARENESS LOST			FIX	EFFECTS
TIME	**SPEAKER**	**MESSAGE**		
0904	Marine 6	Marine 6, that plane was a large bomber-style green aircraft into the second tower, be advised.	None.	None.
0913	Car 9	Car 9 to Manhattan.	Car 9 came back on the radio to correct Dispatch, saying they wanted the mobile command vehicle, not field com	None, corrected before it had an impact.
	DISPATCH	Car 9 go ahead.		
	Car 9	Would you advise the mobile command vehicle to come in on West and Liberty Street, West and Liberty Street.		
	DISPATCH	I already advised them.		
	Car 9	What's their ETA?		
	DIS-PATCH	Manhattan calling Field Comm.		
0930	Engine 317	I've got ... from the Port Authority telling me that the elevators are on the 44th floor. Don't use them, they're about to come down.	None.	**The firefighters working in whichever building the elevators were not coming down in would have had continued access to elevators, but instead were told not to use them because of vague information.**
	DIS-PATCH	**Is that going to be for No. 2 or No. 1 World Trade?**		
		Wasn't sure. I'd say go with both.		
	DIS-PATCH	Attention all companies operating at the fifth alarm for both World Trade Centers, the elevators, the Port Authority reports the elevators on the No. 4-4 floor are about to come down. All companies operating at No. 1 and No. 2 World Trade Center at the fifth alarm, do not use the elevators. They are about to come down as per the Port Authority on the No. 4-4 floor. Field Comm., receive that urgent? Manhattan to Ladder 2-1, K.		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